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For:
METHOD AND APPARATUS FOR DETERMINING THE ADHESION AND ADHESION LIMIT IN THE CASE OF VEHICLE TIRES

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METHOD AND APPARATUS FOR DETERMINING THE ADHESION AND ADHESION LIMIT IN THE CASE OF VEHICLE TIRES

FIELD OF THE INVENTION

The invention relates to a method and an apparatus for determining the adhesion and/or adhesion limit of a tire of a vehicle in motion. In this method and apparatus, the driving state of the vehicle is measured by means of a plurality of driving-dynamics sensors, and the state of the roadway is determined by means of at least one roadway sensor, which detects the state of the roadway. A computer for evaluating the data from the driving-dynamics sensors and the roadway sensor is furthermore provided, the computer using a driving-dynamics simulation model to determine the kinematic state of the wheel and the adhesion or, taking into account at least one stored tire characteristic diagram comprising tire characteristics, the adhesion limit.

BACKGROUND OF THE INVENTION

If a vehicle fitted with tires is in a normal driving state involving comparatively low longitudinal and transverse acceleration values, i.e. not in the region of the driving limit, it has hitherto been impossible to draw reliable conclusions about the adhesion and adhesion limit of tires or wheels, of axles or of the vehicle. There is a large degree of uncertainty as to the size of the adhesion reserves, i.e. the gap between the current horizontal forces (circumferential forces and lateral forces) between the tire and the roadway (the adhesion) and the maximum forces that can be transmitted (the adhesion limit).

In a normal driving state involving comparatively low longitudinal and transverse acceleration values, it has hitherto only been possible to estimate the adhesion and adhesion limit of production vehicles qualitatively on the basis of the driver's experience, and this only very roughly. With this in mind, the driver can, for example, observe that the roadway is wet and instinctively assume a reduction in the adhesion limit compared with a dry roadway on the basis of his experience. However, this is only partially successful, as demonstrated by the increase in the frequency of accidents on wet roads. On production vehicles, there has hitherto been no facility for determining the adhesion and adhesion limit quantitatively at low longitudinal and transverse accelerations.

It has hitherto also been impossible to provide reliable information on the adhesion and adhesion limit as the vehicle approaches the driving limit, i.e. the adhesion limit, where the longitudinal and transverse acceleration values are comparitively higher. On production vehicles there are known systems such as ABS, ASR or ESP which detect when the vehicle is reaching an adhesion limit or a limit in terms of driving dynamics. However, the adhesion and the adhesion limit are determined neither while the vehicle is in a normal driving state nor as it approaches the driving limit.

In the literature reference H.-J. Görich, System zur Ermittlung des aktuellen Kraftschlußpotentials eines PKW im Fahrbetrieb [System for determining the current adhesion potential of a moving passenger car], Fortschritt-Berichte VDI Series 12, No. 181, VDI-Verlag 1993, Düsseldorf, a proposal is made for a system which allows the adhesion and adhesion limit to be estimated in many cases. Here, driving-dynamics sensors supply

information on the driving state. Roadway sensors, each of which is responsible exclusively for a specific roadway, furthermore supply information on the state of the roadway. In addition, extensive measurements incorporated into tire characteristic maps are required for various states of the roadway. Using a simple though not particularly quick vehicle computation model and a vehicle computer which does not allow real-time operation, the current driving state, i.e. the adhesion of the axles and of the vehicle, is compared with the vehicle's adhesion limit determined. The results for the vehicle are represented graphically using a screen in the vehicle.

Although the known system supplies information on the adhesion and the adhesion limit of the vehicle, it has various disadvantages.

One disadvantage is that extensive tire characteristic maps comprising a multiplicity of tire characteristics for all conceivable driving states and states of the roadway are required. These tire characteristics are assumed to be invariable. This leads to the results becoming inaccurate as the tread depth decreases during the operation of the vehicle, for example.

In addition, there is the fact that the states of the roadway are divided only relatively roughly into three groups, namely dry, wet and slippery (as in winter). Within a group, the tire characteristic maps are assumed to be constant. This likewise leads to, in some cases, very inaccurate results since it is known that, in reality, the depth of water on a wet roadway has a great effect, for example. It is furthermore disadvantageous that the adhesion is determined only for each axle and the adhesion and the adhesion limit are determined for the vehicle. This likewise leads to inaccuracies in determination, especially when the wheels are rolling on different underlying

roadway surfaces. There is thus no possibility of calculating the adhesion separately for each individual wheel.

In the literature reference Th. Dieckmann, Ein neuartiger Ansatz zur Bestimmung der Kraftschlußbedingungen im Reifen/Fahrbahnkontakt, Reifen, Fahrwerk, Fahrbahn [A novel approach to the determination of adhesion conditions in tire/road contact, tires, running gear, roadway], Report on the conference of the VDI-Gesellschaft Fahrzeugtechnik, No. 916, VDI-Verlag, 1991, Düsseldorf, and in document DE 3705983 A1 ("Device for monitoring the utilization factor of the coefficient of road friction prevailing in the braking and/or acceleration of a motor vehicle"), a proposal is made for a method in which conclusions are drawn about the maxima of the circumferential forces that can be transmitted from the initial slope of the circumferential-force/slip curves of the wheels and in which conclusions are drawn therefrom about the adhesion and the adhesion limit of the entire vehicle. This principle is relatively inaccurate and has the following disadvantages.

On the one hand, only the circumferential-force properties of the tires are taken into account, allowing only limited conclusions to be drawn about the lateral-force properties.

It has furthermore been found that a sufficiently clear change in the initial slope cannot be recognized in all cases required in practice. Thus, for example, a large difference between the adhesion limits is possible during the transition from a dry roadway to a wet roadway with shallow or moderate water levels, whereas the initial slopes differ only to a small extent.

It is furthermore known that the initial slope of the circumferential-force/slip curves depends not only on the state of the roadway but also on the

properties of the tires, which change, for example, due to a decrease in the tread depth. Since the stored characteristics are fixed and do not take into account changes in the tire properties during operation, it is not possible to draw reliable conclusions about the current adhesion limit from the initial slope.

In document DE 4338587 C2 ("Method for estimating gripping properties of road surface with respect to the wheels of a motor vehicle travelling over it"), the proposal is to measure the torque of the driven wheels and the rotational speed of all the wheels. Moreover, the wheel load acting on the driven wheels is estimated. When the driven wheels reach certain circumferential-slip values and approach the adhesion limit, the current adhesion of the wheels is set to equal the current adhesion limit of the wheels. This is stored in a memory as an instantaneous but temporary estimated value. This stored estimated value is updated as soon as certain conditions are present, if, for example, a driving state involving high circumferential-slip values, in which the adhesion of the wheels is different, is reached again. In this way, the adhesion and adhesion limit of wheels is determined, and it is possible to draw conclusions about the adhesion and adhesion limit of the vehicle.

However, this proposed principle has the disadvantage that sufficiently accurate estimation is only possible if the vehicle comes within the immediate vicinity of the driving limit. In normal driving states, determination cannot be carried out.

The stored adhesion limits can furthermore only be updated if certain criteria, e.g. high circumferential-slip values, are met. Since this is the case

only in infrequent driving states, the stored values cannot be updated continuously and thus reliably, despite continuous operation of the system.

According to this document, provision is furthermore made for the torque acting on the driven wheels to be measured. This measurement is relatively involved and must operate equally during braking and acceleration. There is furthermore the fact that only the adhesion limit of the tires is estimated, without information on the shape of the full tire characteristic being supplied.

The prior art furthermore includes systems which have been investigated within the context of research projects. They allow either only qualitative verdicts on the adhesion and the adhesion limit or, to detect the state of the roadway, require complex sensors which are unsuitable for practical applications or involve unacceptably high costs if used on production vehicles.

The object on which the invention is based is to provide a method and an apparatus by means of which, an accurate approximation of the current adhesion and/or the current adhesion limit of a tire or of axles of a moving vehicle can be determined in as far as possible for every driving state, even at comparatively low longitudinal and transverse acceleration values. It should thus be possible to determine the current adhesion limit well before it has been reached. It is furthermore desirable if the associated tire characteristic maps can be prepared for a comparatively low outlay.

The invention provides reliable and accurate information on the current adhesion or current adhesion limit in a manner which allows as little outlay as possible. This information can then be made available to the driver, for

example, or passed to a system which performs a control intervention in a driving or braking operation.

To achieve this object in the case of a method and an apparatus of the type stated at the outset, the invention provides for the tire characteristics (for various states of the roadway and, for example, for various wheel loads) to be adapted to the current tire behaviour in the course of operation, starting from an initial set of basic tire characteristics.

In the method according to the invention, the current adhesion, in particular the circumferential and lateral forces, and the kinematic state of the wheel, in particular the circumferential-slip and slip angle, are calculated continuously with the aid of the computer, the driving-dynamics simulation model and the signals of the driving-dynamics sensors. The current adhesion limit is furthermore determined by first of all carrying out roadway detection and then selecting associated tire characteristics (e.g. for various wheel loads) from a tire characteristic-map memory and, finally, after tire-characteristic adaptation, determining the current adhesion limit.

In this method, the driving-dynamics sensors supply measurement data about the kinematic state of the vehicle and, possibly, about the forces or moments acting on the vehicle. They are used as input variables for the simulation calculations of the computer by means of the driving-dynamics simulation model. The output variables supplied by the simulation calculations are the current adhesion and the kinematic state of the wheels. These variables constitute output data from the system and can also be used for determining the current adhesion limit.

In principle, the state of the roadway (e.g. dry, wet, snow etc.) can be determined in a manner known per se by means of one or more roadway sensors. However, one disadvantage with this is that the decision as to which state of the roadway is present depends in each case on the correct and reliable operation of a particular specific sensor for the respective state of the roadway or on a particular evaluation variable. If one sensor is malfunctioning or an evaluation variable is incorrect, the corresponding roadway can therefore no longer be identified.

In order to ensure accuracy of determination, the state of the roadway should be detected accurately and reliably. For this purpose, it is proposed, in accordance with a preferred additional feature, that the state of the roadway is determined by means of a plurality of different roadway sensors, the information derived from their signals being evaluated by means of a bound method for delimiting the state of the roadway. In addition to the information on the state of the roadway determined by the roadway sensors, it is also possible for results from the driving-dynamics simulation calculation to be evaluated in the bound method. One example of a piece of information that can be taken into account in the bound method is, for instance, the initial slope of the actual adhesion curve, which can be determined by means of the driving-dynamics simulation calculation.

In the bound method, a multiplicity of pieces of information of different kinds is superimposed, allowing particular states of the roadway to be excluded on the basis of existing combinations of sensor signals or other information, the correct state of the roadway thus finally being identified as the result of logical combination of the existing information. This is not to be

confused with a system incorporating a redundant arrangement of roadway sensors, in which a number of different sensors are intended to sense the same state of the roadway independently of one another. In the bound method that is advantageously employed, different pieces of information are collected and the state of the roadway is inferred by combination of these pieces of information.

If the state of the roadway has been determined by means of the bound method, for example, the associated tire characteristic diagram (comprising characteristics for various wheel loads for example) or the associated tire characteristic can be selected from a tire characteristic-map memory. Selection can be assisted by information from the driving-dynamics sensors. When an apparatus according to the invention is first put into operation, a basic tire characteristic diagram containing an initial set of basic tire characteristics stored in the computer for a small number of different tire/roadway combinations is taken as a starting point.

In the course of the operation of the vehicle, these basic tire characteristics are adapted to the current tire behaviour by correcting the individual characteristics. This is possible because the system is constructed in such a way that it detects a change in the adhesion behaviour due to a change in tire properties, e.g. due to a change in tread depth, in the course of operation from the fact that, in this case, the current adhesion and the kinematic state of the wheels do not match the selected characteristic diagram or the selected characteristic. The correction can be repeated each time a deviation is detected.

The adaptation of the tire characteristics can thus preferably take place when a deviation in the current adhesion in the existing kinematic state of the wheel from the selected tire characteristic is detected on the basis of a comparison between the results of the driving-dynamics simulation model and the state of the roadway determined.

The basic tire characteristic maps or the tire characteristic maps preferably contain only a small total number of tire characteristics (for various states of the roadway and, for example, various wheel loads) to be taken into account in the driving-dynamics simulation calculation, preferably fewer than 40, particularly preferably fewer than 20 tire characteristics. In accordance with an additional advantageous feature, however, provision can be made for one or more tire characteristic maps to be supplemented in the course of operation by tire characteristics for further states of the roadway which were not included in the basic tire characteristic maps and have proven useful. To this extent, the system can be capable of learning and can be designed to be adaptive.

If it is the case both that the current state of the roadway has been identified and the associated tire characteristic has been selected by the system and adapted to the current tire behaviour, the adhesion limit can be determined before it has been reached. Using the method according to the invention, it is thus possible to determine the adhesion and adhesion limit more accurately than was hitherto possible. One advantage of the preferred bound method is that the state of the roadway can be detected more reliably, redundant detection being possible.

In a preferred embodiment of the invention, it is furthermore advantageous that a change in the adhesion behaviour caused by a change in tire properties, e.g. by the change in tread depth, in the course of operation can be detected. In addition, only a small number of basic tire characteristic maps or basic tire characteristics is required and these can be adapted and, if appropriate, supplemented in the course of operation.

According to another advantageous feature, it is proposed that the driving-dynamics simulation model is a real-time model, by means of which the computer calculates the current kinematic state of the wheel and/or the current adhesion and/or the current adhesion limit of the wheel in real time. A driving-dynamics simulation model of this kind, which operates in real time, can be created, for example, by means of rapid, compact differential equations using knowledge on the dynamic behaviour of the vehicle concerned.

If the driving-dynamics simulation model used is designed specifically for real time, the current adhesion calculated in real time using this model and the kinematic state of the wheels can advantageously be used as an input variable for a mechatronic control system which performs control interventions in the handling. If the current adhesion is calculated separately for each wheel, the results can be used, for example, for optimized control of the driving dynamics, thereby making it possible to better ensure the stability of the vehicle in critical driving situations.

These data can also be used in an advantageous manner by mechatronic control systems through determination of the adhesion limit in real time. In this case, for example, a mechatronic brake system can respond

more rapidly to changing roadway grip in the event of full braking. If the adhesion limit is determined individually for each wheel, a difference in the grip for the wheels of one axle can be taken into account even as a braking operation is being initiated.

The adhesion and/or the adhesion limit is/are therefore preferably determined for the individual wheels of the vehicle or separately for the wheels of an axle since the kinematic state and critical driving behaviour can thereby be detected more accurately. This provides favourable preconditions for a system which, for example, gives the driver a warning or performs a control intervention in the handling. Determining the adhesion limit separately for individual wheels makes it possible to estimate more accurately whether, owing to different adhesion limits at the individual wheels, critical handling behaviour of the vehicle is to be expected when the vehicle is approaching the driving limit. In this case, it is possible, for example, for a warning to be issued to the driver while the vehicle is still a relatively long way from the driving limit. In the case of individual calculation or evaluation of the wheels of an axle, it is also possible to detect and take account of the case where the wheels have different friction coefficients due, for example, to differences in the state of the roadway.

However, in many embodiments it can also be advantageous if the adhesion and/or the adhesion limit is/are determined for each axle, the wheels of an axle being treated equally, or if the adhesion and/or adhesion limit of the entire vehicle is determined by means of the particular adhesion values and/or adhesion limits of all the wheels. Calculating the adhesion or adhesion limit of the entire vehicle is suitable for allowing the driving state or driving limit of the

vehicle to be described in a simple and easily comprehensible manner. The driver can, for example, be informed during the journey using a suitable representation of the adhesion or adhesion limit.

Within the context of the present invention, it has surprisingly been found that the extremely difficult requirements involved in determining the adhesion or adhesion limit of a tire with sufficient accuracy can be met for a relatively low outlay without the need for a high technical outlay involved in providing a multiplicity of tire characteristic maps or of tire characteristics or for the determination of the state of the roadway, as was previously thought necessary. The invention thus achieves aims which have long been pursued by those skilled in the art.

In order at the same time to achieve particularly good results, the features explained above and the features of the exemplary embodiments below can advantageously be employed singly or in combination, and additional advantageous effects may be obtained from the interaction of features according to the invention.

The invention will be explained in greater detail below with reference to exemplary embodiments, which are illustrated schematically in the figures and which reveal further following features and characteristics.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 illustrates an embodiment of a method for detecting the adhesion and the adhesion limit;

Fig. 2 illustrates an embodiment of a bound method for determining the state of the roadway;

Fig. 3 illustrates an embodiment of a tire characteristic diagram including five tire characteristics; and

Fig. 4 illustrates an embodiment of a high-precision adaptation of a tire characteristic.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

As regards the meaning of the terms used in the text of this application, attention is drawn to the following supplementary literature: DIN 70000; DIN 44300; J. Reimpell-K. Hoseus, Fahrwerktechnik: Fahrzeugmechanik [Suspension technology: Vehicle mechanics], Vogel Buchverlag 1992; A. Zomotor, Fahrwerktechnik: Fahrverhalten [Suspension technology: Handling], Vogel Buchverlag 1991. Although some of the terms used in these literature references differ from one another slightly, the person skilled in the art will be able to allocate the correct meaning to them without difficulty.

Fig. 1 shows a flow diagram intended to illustrate more specifically an embodiment of the mode of operation of a system according to the invention for determining the adhesion and the adhesion limit for each individual wheel of a vehicle. The word "adhesion" is here intended to denote the resultant of the circumferential force and the lateral force acting on the wheel, i.e. the adhesion is described by two forces or their resultants. The term "adhesion limit" is intended to denote the maximum possible circumferential force and lateral force which can be transmitted in the current driving state and with the current roadway surface. The adhesion limit is thus described by two forces.

In this context, the circumferential force u is the component of the ground reaction force in the direction of the X_W axis (DIN 70000), i.e.

obviously the force (motive or braking force) in the longitudinal direction of the wheel in the centre plane of the rim and in the plane of the roadway. The lateral force is the component of the ground reaction force in the direction of the Y_W axis (DIN 70000), i.e. obviously the force transverse to the wheel, perpendicular to the longitudinal direction of the wheel, in the plane of the roadway.

The system illustrated schematically in Fig. 1 performs two main tasks. The left-hand part of the flow diagram shows system components used to calculate the current adhesion 4. The right-hand part shows the system components by means of which the current adhesion limit 8 is determined before this limit is reached. However, the adhesion limit 8 is not determined independently of the current adhesion 4. There is data exchange between the left-hand part and the right-hand part.

The system comprises two groups of sensors. One group comprises driving-dynamics sensors 1, which supply data on the state of the vehicle with respect to its driving dynamics. The other group comprises roadway sensors 2, which supply data on the state of the roadway.

The driving-dynamics sensors 1, some of which may already have been fitted as standard in the motor vehicle, supply, for example, measurement data on the longitudinal acceleration of the vehicle, the transverse acceleration, the roll angle, the pitch angle, the yaw angle, the rotational speeds of the individual wheels and the wheel loads of the individual wheels.

It is also possible to determine individual variables indirectly, rather than measuring them directly. In general terms, it is possible to include in the

method driving-dynamics variables derived from data measured by means of the driving-dynamics sensors. For example, it is possible for the yaw angle to be determined by integrating the measured yaw rate or for the wheel load to be determined indirectly by measuring the compression travel of the wheels relative to the body rather than measuring the wheel load. It is also possible, for example, for measurement of the wheel loads of the wheels of an axle to be replaced by measurement of the axle load, which is apportioned to the individual wheels using data from the driving-dynamics sensors 1, in particular the roll angle.

It is also possible, for example, for measurement of the wheel loads to be replaced by determination of the total weight. The total weight can be determined, for example, by measuring the drive torques and using the measurement signals of the acceleration sensor in the longitudinal direction. In this case, it is possible, using data from the driving-dynamics sensors 1, in particular the pitch angle, to perform apportioning to the axle loads and, in particular by means of the roll angle, to perform apportioning to the individual wheel loads.

The data from the driving-dynamics sensors 1 and variables which may, if appropriate, have been derived indirectly therefrom are passed to the driving-dynamics simulation model 3, which is operated in real time. Real-time systems are distinguished by the fact that they can process external events within a predetermined time and thus comply with the external time conditions (DIN 44300). This means that, in real-time simulation, the calculated dynamic phenomenon corresponds at every point in time to the phenomenon which

has actually occurred. There is no significant delay separating the behaviour of the real-time system from the behaviour of the real system.

Using the driving-dynamics simulation model 3, the circumferential forces currently acting on the individual wheels, the circumferential-slip values, the lateral forces and the slip angle are calculated. The term "circumferential slip" is here taken to mean the variable $S_{X,W}$ in accordance with DIN 70000, which clearly describes the slip between the tire and the roadway that occurs during braking or propulsion since, for the same vehicle speed, the wheel rotates more slowly during braking and more rapidly during propulsion than in the free-rolling state. According to DIN 70000, the slip angle is the angle between the X_W axis and the tangent to the curve of the path of the wheel contact point and describes clearly the angle between the longitudinal direction of the wheel and the vector for the rate of travel of the centre of gravity of the wheel.

As the output variable, the driving-dynamics simulation model 3 supplies the current adhesion 4 for the individual wheels. The output data of the driving-dynamics simulation model 3 including the following variables - longitudinal acceleration, transverse acceleration, roll angle, pitch angle, yaw angle, rotational speeds of the wheels and wheel loads - are also passed to the roadway detection component 5 and the characteristic adaptation component 6.

The roadway sensors 2 supply data on the temperature of the roadway and/or on the state of the roadway, for example, using optical or acoustic methods for example. It is also possible to employ sensors which give only a yes/no output, as to whether the roadway is dry or not for example.

The data from the roadway sensors 2 are processed by the roadway detector 5, which also receives results from the calculations by the driving-dynamics simulation model 3. These results of calculation are used for roadway detection if the current operating points in the tire characteristic are in the linear range of the circumferential-force/slip and lateral-force/slip-angle curves, i.e. if the vehicle is travelling with comparatively low longitudinal and transverse acceleration. Using the current operating points, it is possible in this case to determine the initial slope of the circumferential-force/slip and/or the lateral-force/slip-angle characteristic under consideration. In DIN 70000, the slope of the circumferential-force/slip curve is referred to as the circumferential-force/circumferential-slip gradient. The initial slope of the circumferential-force/slip curve is equivalent to the circumferential-force/circumferential-slip gradient at the circumferential force 0.

These initial slopes and data on the temperature of the roadway and the state of the roadway are thus available by optical or acoustic methods to allow the state of the roadway to be determined. The state of the roadway can then be identified using a bound method. Since there is at least partial redundancy in the state of the roadway in the identification of the state of the roadway, it is possible in many cases to carry out a plausibility check. If, for example, a large depth of water has been identified on the basis of the optical or acoustic methods, the temperature of the roadway should not simultaneously be very low. If this is nevertheless the case, it can be concluded from this that the roadway detector is faulty, and the system is switched off. As an alternative, there is also the possibility of giving certain

signals priority, the system thus remaining active and merely outputting a fault message.

If the roadway detector 5 is operating correctly, the state of the roadway determined is passed to a characteristic-map memory 7, and in one embodiment, the state of the roadway is passed separately for each wheel. The characteristic-map memory 7 furthermore receives information from the driving-dynamics sensors 1, in particular on the wheel load of the wheel for the selection of the appropriate tire characteristic.

To increase accuracy, further parameters can be taken into account, e.g. the influence of the camber angle. Since this is generally not measured in vehicles, it is possible to use a substitute dependency on a measured variable or on a combination of measured variables, e.g. wheel load and transverse acceleration. Finally, the information from the roadway detector 5 and the driving-dynamics sensors 1 are used to select a suitable tire characteristic diagram (for different wheel loads, for example) and, from this, a suitable tire characteristic, preferably for each individual wheel separately.

The selected tire characteristic (or a tire characteristic diagram) is passed to the characteristic adaptor 6. Since the characteristic adaptor 6 also receives the output data from the driving-dynamics simulation model 3, it is possible to check whether the current adhesion 4 and the kinematic state of the individual wheels matches the selected tire characteristics. If this is not the case, the tire characteristic or the tire characteristic diagram is corrected by adapting individual characteristics, which are stored in the characteristic-map memory 7.

However, the adaptation does not have to be limited to the selected tire characteristic 10; on the contrary, it is also possible while adapting one tire characteristic to adapt one or more further tire characteristics of one or more tire characteristic maps 9 accordingly. Adaptation of further, so to speak "neighbouring", tire characteristics can be performed on the basis of theoretical or empirical knowledge of tire characteristic maps, for example.

One reason for this correction or adaptation can be that the properties of the tires have changed over the period of operation of the vehicle, owing to a decrease in tread depth for example. A change in the properties of the tire due to a tire change is also detected and corrected by the simulation calculation. If the current adhesion 4 differs from the selected tire characteristic, it is advantageously possible here for the correction or adaptation of the characteristic to be carried out approximately in normal driving states and to be carried out with high precision in the vicinity of the driving limit, this being explained in conjunction with Fig. 4.

The characteristic adaptor 6 outputs tire characteristics which have been corrected or adapted for the wheels, these characteristics also being passed back to the characteristic-map memory 7 for storage. Since the adhesion limit 8 is described by the maxima of the individual tire characteristics, it is thus known approximately when the vehicle is in a normal driving state. Insofar as the accuracy of characteristic adaptation is increased when the vehicle is approaching the driving limit, the adhesion limit is known with greater accuracy in the boundary zone.

Fig. 2 shows a table to explain in greater detail the procedure involved in roadway detection 5 using a bound method. In a bound method, the state of

the roadway is not measured precisely but delimited by means of various pieces of information. For this purpose, information which allows conclusions to be drawn about the state of the roadway is gathered. The more information that is available, the more precisely the state of the roadway can be defined. Evaluating a single piece of information, it is possible for the state of the roadway to be delimited only very roughly at first. If further information is evaluated in addition, the delimitation becomes more and more precise, even if the individual pieces of information, considered on their own, allow only rough delimitation.

On the left-hand side of Fig. 2, there are lines listing information on the state of the roadway, it being possible for this information to stem from roadway sensors 2 or from the evaluation of the calculation using the driving-dynamics simulation model 3. This information preferably comprises at least three of the following types: air temperature, roadway temperature, optical or acoustic detection of snow, optical or acoustic detection of ice, optical or acoustic detection of water or optical or acoustic detection of a dry roadway. The particular pieces of information can, for example, be in the form of analogue measured variables, digital information (yes/no) or as a qualitative indication (deep, moderate, low).

The columns show, by way of example, various states of the roadway, which are assumed to be unknown and which are to be determined by the roadway detector 5. These states of the roadway can preferably include three or more of the following: dry, damp, wet, shallow water, deep water, snow, ice, loose underlying surface.

If the measurement of the roadway temperature supplies the information "very low temperature", for example, and the roadway sensor for detecting snow and ice supplies a positive signal and the evaluation of the initial slope of the circumferential-force/slip curve shows that the initial slope is shallow, the only possibility according to the pattern of crosses is that the roadway is covered in snow. This result is obtained even though a roadway sensor 2 that detects specifically only the covering of the roadway by snow is not used. This bound system is furthermore redundant to a certain extent since, at least in some cases, the results can simply be checked. If, for instance, the sensor for determining roadway temperature fails in the example described, the covering of the roadway by snow can be identified by means of the two remaining pieces of information.

Fig. 3 shows a tire characteristic map 9 by way of example, the said map containing a plurality of tire characteristics 10 for various states of the roadway. A tire characteristic 10 is a curve in the tire characteristic map 9, and can be used to represent the circumferential force U as a function of the slip s or the lateral force as a function of the slip angle. In general terms, a tire characteristic map 9 is a diagram in which a number of tire characteristics 10 for different parameters are illustrated. For example, the tire characteristic map 9 can illustrate circumferential-force/slip or lateral-force/slip-angle curves for various wheel loads, all the other parameters being held constant. Another possibility, as in Fig. 3, is circumferential-force/slip curves for various roadway surfaces, for example.

In one embodiment, the state of the roadway and/or the wheel load are taken into account as the parameters of the tire characteristic 10 or tire

characteristic map 9. Further or different advantageous parameters may be the transverse acceleration, the longitudinal acceleration, the rotational speed of the wheels or the camber angle, for example.

It is advantageous if, when the system is first put into operation or after intentional resetting to initial values, for example, the tire characteristic maps 9 contain a basic set of characteristics 10 which does not as yet cover all conceivable parameter combinations. The basic tire characteristics form a basic tire characteristic diagram in which tire characteristics for a small number of states of the roadway and/or wheel loads, for example, are stored in simplified general form. When the system is first put into operation, only a small number of basic tire characteristics can be stored for a small number of different tire/roadway combinations. These characteristics apply to an average tire and do not accurately represent the behaviour of the tire actually fitted. Its actual behaviour depends, inter alia, on the type of tire, the state of the tread, the tire pressure and other parameters.

The basic characteristic maps are sufficient since a correction or adaptation of the characteristics 10 stored is carried out in the system according to the invention. The state of the roadway is taken into account during this process. It is furthermore also advantageous if the tire characteristic maps 9 are supplemented by further tire characteristics 10. Parameter combinations that are lacking can here initially be covered by interpolation, being replaced in the course of vehicle operation by their own tire characteristics 10.

It is advantageous if provision is made for the tire characteristic maps 9 to comprise at least three basic tire characteristics or tire characteristics 10 for

the following states of the roadway: dry, damp, wet, shallow water, deep water, snow, ice, loose underlying surface. The effect of wheel load and the interaction between the circumferential and the lateral forces can be taken into account on the basis of empirical values, for example.

Since the actual behaviour of a tire does not coincide precisely with the behaviour described by the basic characteristics, the tire characteristics 10 and thus also the tire characteristic maps 9 are adapted during operation, a change in tire behaviour due, for example, to wear also being taken into account. As long as the operating states are normal, with comparatively low longitudinal and transverse accelerations in combination with comparatively low circumferential-force/slip and slip-angle values, an approximate adaptation of the tire characteristics 10 can be performed as soon as a deviation between the current adhesion (in a kinematic state of the wheel) and the selected tire characteristic is detected, and an approximate determination of the adhesion limit 8 can thus be carried out. This is possible even though the exact shape of the actual tire characteristic 10 in the range of high circumferential-force/slip and slip-angle values, i.e. comparatively high circumferential and/or lateral forces, is not yet known.

Fig. 4 illustrates how the adaptation of the tire characteristics 10 and the determination of the adhesion limit 8, 8a are carried out accurately in the region of the driving limit of the vehicle in accordance with a particularly advantageous feature of the invention. This highly accurate adaptation takes place as soon as the vehicle approaches the driving limit and the current adhesion 4 and the kinematic state of the wheels possibly no longer match

the selected tire characteristic 10. As a result, the calculation of the adhesion limit 8 becomes more accurate as the vehicle approaches the driving limit.

The adaptation of the tire characteristic 10 can generally be performed as soon as deviations between the calculated current operating point 11 and the tire characteristic 10 originally selected from the characteristic-map memory 7 occur. In this context, the operating point 11 describes the driving state of a vehicle or a tire with which a particular circumferential force U, a particular circumferential slip s, a particular lateral force and a particular slip angle can be associated. Within the context of the invention, the position of the operating point in a tire characteristic map 9 or on a tire characteristic 10 is not necessarily determined by measuring the circumferential force U and slip s or lateral force and slip angle directly, the said variables instead being derived from the driving-dynamics simulation model 3, the selection of the tire characteristic 10 involving the roadway detector 5.

The initial region 12 of the tire characteristic 10 can be regarded to a large extent as approximately linear. Particularly in the initial region, the adaptation of the tire characteristic 10 or determination of the adhesion limit will be approximate.

At higher slip values, i.e. in the vicinity of the approximately applicable adhesion limit 8a, which is determined by the maximum of the tire characteristic 10 selected, the selected characteristic 10 leaves the linear region, however. In this region too, deviation of the selected characteristic 10 from the actually valid characteristic 14, from which the actual adhesion limit 8 can be determined, can be detected from the fact that the operating point 11 does not lie on the selected tire characteristic 10 but deviates from it. In the

nonlinear case, this is the case for operating points 11 which lie above the deviation point 13.

The deviation point 13 is the point on the selected tire characteristic 10 from which the actually valid tire characteristic deviates from the selected tire characteristic 10 or from a linear shape in the direction of increasing slip or slip-angle values. The region from which the operating point 11 deviates from the tire characteristic 10 or from a linear shape is indicated in Fig. 4 by an upward-pointing arrow.

A soon as the operating point 11 no longer lies on the selected tire characteristic 10, the selected tire characteristic 10 is corrected, giving a new, corrected, tire characteristic 14. This adapted tire characteristic 14 then deviates, for example, from the originally selected characteristic 10, likewise from the deviation point 13. The adaptation can take place approximately already in the linear initial region. The detection of a deviation in conjunction with exact adaptation of the tire characteristic and determination of the adhesion limit is preferably possible when the linear initial region 12 has been exceeded. However, exact adaptation of the tire characteristic and determination of the adhesion limit are possible not only in the immediate vicinity of the adhesion limit but are possible at a relatively early stage in the wider vicinity of the adhesion limit.

Deviation of the operating point 11 from the selected tire characteristic 10 or deviation of the tire characteristic 10 from the linear initial region can be used for sliding correction of the characteristic, each deviation being used for a correction. However, in many embodiments it can also be

expedient if a correction is only carried out when the deviation exceeds a particular threshold.

When a deviation is detected, the selected tire characteristic 10 can be converted to a corrected tire characteristic 14, it being possible for this to be accomplished using the theoretical or empirical knowledge of neighbouring tire characteristics or of the fundamental behaviour of vehicle tires. Since adaptation of the tire characteristic 10 to give a corrected tire characteristic 14 can be performed more accurately particularly when the vehicle is approaching the driving limit, the accuracy of determination of the adhesion limit 8 is increased in the region of the adhesion limit 8 or driving limit.

In this way, approximate adaptation of the tire characteristic maps in operating situations involving comparatively low longitudinal and transverse accelerations and accurate adaptation of the tire characteristics during each approach to the driving limit is possible, irrespective of whether the driving situation is critical or not. During normal driving operation, the current adhesion limit is estimated continuously in an approximate manner. When the vehicle approaches the limiting range, determination of the current adhesion limit becomes more accurate. This means that precise data are available as soon as an exact intervention in the handling behaviour becomes necessary.

The invention provides reliable and accurate information on the current adhesion and the current adhesion limit before the adhesion limit has been reached. It is particularly advantageous here that not only the current adhesion limit but also the shape of the valid tire characteristic is available to allow extrapolation of the vehicle behaviour and, in the event of a vehicle control operation, optimum quality of control.